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by

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THE ROLE OF $C_{n\beta.dyn}$ IN THE AIRCRAFT STABILITY AT HIGH ANGLES OF ATTACK

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ABSTRACT [Translated from Chinese]

This paper uses concrete examples of calculations to analyze the reliability of $C_{n\beta.dyn}$ as a stability criterion at high angles of attack, and makes deductions regarding the errors that may result from the use of this criterion. We obtain results that will be of value in the use of this criterion. Key words: Stability at high angle of attack, aeronautics derivatives.

ABSTRACT [Originally in English, transcribed verbatim]

In order to predict the aircraft stability at high-angles-of-attack, some criteria were suggested and $C_{n\beta.dyn}$ is one of the most important criteria. Some surveys about correlations of $C_{n\beta.dyn}$ with flight tests and authors opinion, the divergence can be predicted in most cases when $C_{n\beta.dyn}$ is negative. An example is given to explain the effects of some of the aerodynamic derivatives on the aircraft stability. These derivatives are connected with $C_{n\beta.dyn}$. Time history studies are carried out in this paper by programming, on a digital computer, a set of equations of motion pertinent to a typical fighter, by varying some of the aerodynamic derivations in a predeterminate manner, and by observing the responses of some of the variables of motion to derivatives applied to the set of equations. From the calculating results, we can see that the aircraft could be unstable at high-angles-of-attack even the criterion is still satisfied. In the last part of this paper, we try to give some reasons to explain why these exceptions do exist. Key words: Stability at high-angle-of-attack, aeronautics derivatives.

1. INTRODUCTION

In theory, it is possible to use many methods to handle the problem of non-linear stability at high angles of attack. In recent years, widespread use has been made of the differential equation divergence point theory method. Nevertheless, in the designing stages of aircraft, when the whole range of angle-of-attack aeronautics derivatives is not available, it is still difficult to use this method directly. In order to predict the stability of an airplane at high angles of attack, several simplified semi-empirical norms obtained from a linearized hypothesis are widely used abroad [1, 2]. In these norms, the criterion $C_{n\beta.dyn}>0$ is advanced first. It is generally believed that as long as there is compliance with $C_{n\beta.dyn}>0$, it is by and large possible to satisfy the stability requirements for high angles of attack. In the literature [3], the criterion $C_{n\beta.dyn}>0$ is applied to the statistical values of tests with 28 kinds of airplanes or models to show that it provides an excellent standard for the high-angle-of-attack stability of 20 kinds of airplanes (71.4%), that it provides a good standard for 5 kinds of airplanes (17.9%), and that it is in error for 3 kinds (10.7%).

This paper, by varying several aeronautics derivatives, makes observations of the time variation history of motion parameters in order to establish experimentally the accuracy of the criterion $C_{n\beta.dyn}$. We also discuss the reasons for the shortcomings in the application of this criterion and make several suggestions for improvement.

2. SIMULATION CALCULATIONS FOR TIME-HISTORY

The study of the time-history of motion parameters is the most reliable method for quantified investigation of system stability; it is also an effective checking measure for a variety of theoretical methods [5, 6]. After the airplane's initial flight state is established, we first iteratively establish the plane's equilibrium parameters; we then introduce the operating terms, and calculate the time-history of the flight condition parameters of the plane under different aeronautics derivatives. In the calculations, we

consider the effect of the engine; the air is relegated to the corresponding static condition; the motion equation set, in addition to the dynamics and kinematics equations, also employs the directional cosine to establish the Euler angles ψ, φ, and ϑ, and the ground speed h.

A. Initial Calculation Data:

Airplane weight W=5443.2 kg

Wing surface S=16.15 m²

Wingspread b=7.696 m²

Average aerodynamic chord $\bar{c}$=2.356 m

$I_x = 362.2 \mathrm{kg \cdot m \cdot S^2}$

$I_y = 4189.2 \mathrm{kg \cdot m \cdot S^2}$

$I_z = 4465.7 \mathrm{kg \cdot m \cdot S^2}$

$I_{xz} = -26.27 \mathrm{kg \cdot m \cdot S^2}$

B. Aeronautics Parameters. All aeronautics derivatives and coefficients appearing in the formula set are given in the computer program. The range of the angle of attack α is -10° to 90°; the range of the angle of yaw is -40° to 40°. With high angles of attack, even if $\beta=0$, C_l, C_n and C_y, etc., are still not zero; this is related to the appearance of asymmetrical eddying. At this time, between the vertical and horizontal motion, there exist both an inertial cross effect and an aeronautic cross effect.

C. Initial Conditions. Assume that the plane is flying level at Ma_0=0.7 and H_0=15,400 m. From time zero, the elevators make abrupt stepwise changes and $\Delta\delta_T$=-8°; afterwards, all control surfaces are maintained constant.

3. CALCULATED RESULTS

$C_{n\beta.dyn}$ is defined as follows: $$C_{n\beta.dyn} = C_{n\beta}\cos\alpha - \frac{I_z}{I_x} C_{l\beta}\sin\alpha \qquad (1)$$

When the value for α is set, $C_{n\beta}$ and $C_{l\beta}$ can be found from the aeronautics coefficient graph, and $C_{n\beta.dyn}$ can be calculated from formula (1), as shown in Table 1.

Table 1. $C_{n\beta.dyn}$ at Different Angles of Attack

α(度)(1)	0	8	16	20	24	30
$C_{n\beta}(\beta=0)$	0.00454	0.00478	0.00406	0.00192	0.00032	0.00272($\Delta\beta<0$) −0.00083($\Delta\beta>0$)
$C_{l\beta}(\beta=0)$	−0.0011	−0.00204	−0.00267	−0.00228	−0.00223	−0.0048($\Delta\beta<0$) −0.00208($\Delta\beta>0$)
$C_{n\beta.dyn}$	0.00454	0.00662	0.0130	0.0114	0.0115	0.0319($\Delta\beta<0$) 0.0121($\Delta\beta>0$)

Table 1, Key: (1) Degrees.

Because the graphs for C_l-β and C_n-β are not smooth at angles of attack below 30°, there exist two derivative values.

Several important flight parameter changes after δ_T is brought to bear are shown on Fig. 1. Fig. 1 shows the *Ma* number, the altitude *H*, the angle of attack α, the angle of yaw β, the angle of roll/rotation ϕ, the flight path side angle γ, the azimuth angle ψ (assume $\psi_{t=0}=0$), and the components of the rotational angular speed *p, q* and *r* around the axis of the plane. Graphs using the "+" sign indicate corresponding parameter changes induced by the addition of $\Delta\delta_T$ with the initial data constant. From the graphs, it can be seen that angle α exhibits oscillation after level-tail deflection, with a maximum instantaneous value reaching 21°. But the attenuation of this oscillation is relatively rapid; after 20 seconds, new equilibrium conditions are achieved. During this process, the other parameters generally remain constant. It can be clearly seen from Fig. 1 that the airplane at this time is stable. Correspondingly, it can be seen from Table 1 that $C_{n\beta.dyn}>0$ over the entire range of angle of attack, and furthermore that $C_{n\beta.dyn}$ is greater than the 0.004 laid down in the literature [1]. For this reason, $C_{n\beta.dyn}$ is an accurate criterion for determining stability under these conditions.

Below, we evaluate the applicability of the $C_{n\beta.dyn}$ criterion by observing the flight parameters when several derivative values are varied.

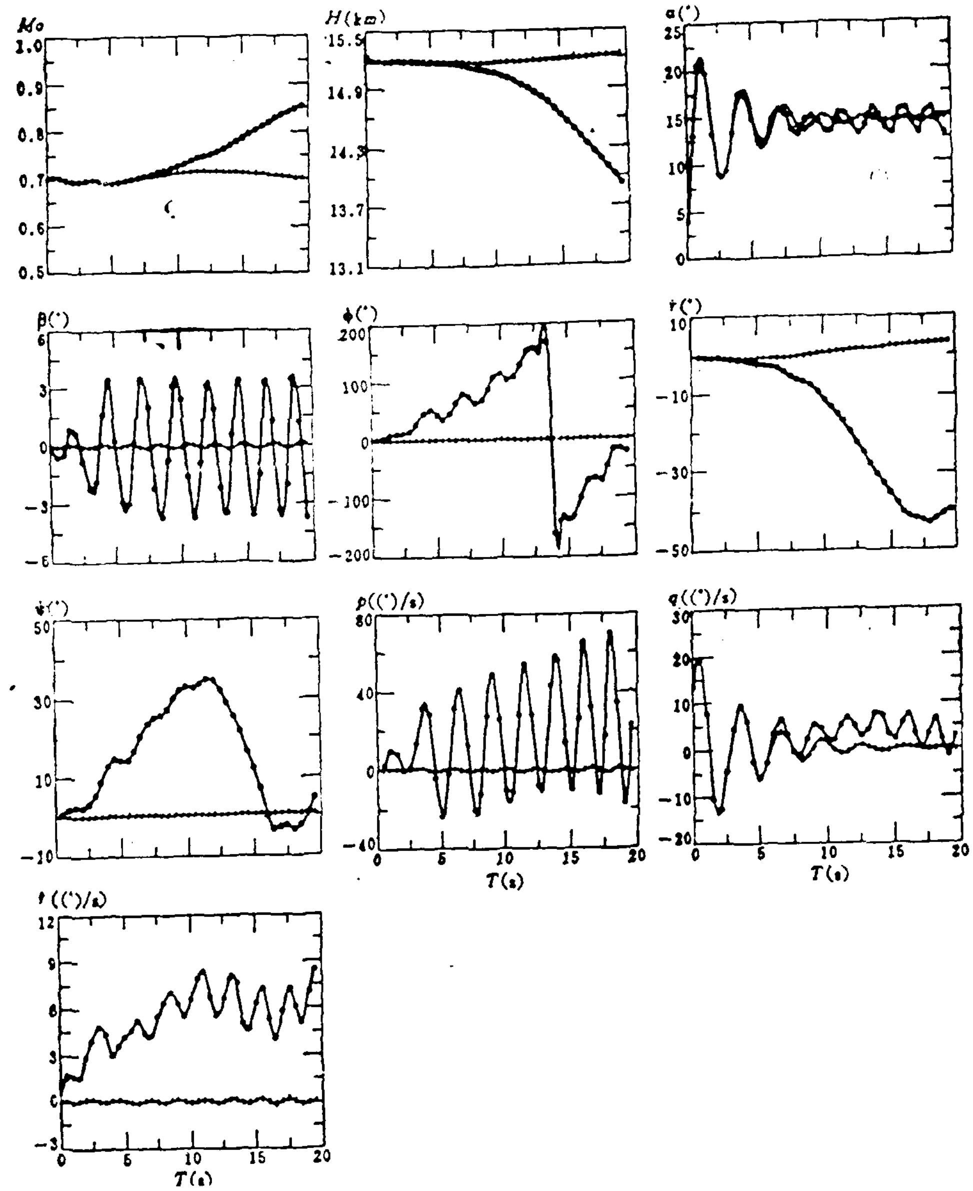

Fig. 1. The effect of $C_{n\alpha}$ [sic].

A. The Effect of $C_{n\beta}$. Assume $C_{n\beta}=0$. It can be seen from formula (1) that, because the previous term is zero, $C_{n\beta.dyn}$ decreases greatly; but it can be seen from Table 2 that within the practical range of the angle of attack $C_{n\beta.dyn}$ is still a positive value, and that the airplane should be stable.

Table 2. The Value of $C_{n\beta.dyn}$ When $C_{n\beta}=0$.

α(度)(1)	0	8	16	20	24	30
$C_{n\beta.dyn}$	0	0.00184	0.00834	0.00984	0.0115	0.0292($\Delta\beta<0$) 0.0130($\Delta\beta>0$)

Key for Table 2: (1) Degrees.

The graphs composed of the symbol "." in Fig. 1 show the time-history of related parameters when $C_{n\beta}=0$. From these graphs, it can be seen that even if, when $C_{n\beta}=0$, all the other aerodynamic data are constant and $C_{n\beta.dyn}$ is a positive value, the airplane nevertheless is not stable. At this time α and β oscillate rapidly with a frequency cycle of about 3 seconds. The airplane's angle of inclination ϕ gradually increases; within 20 seconds the plane has almost made a 360° rotation around the *x* axis, and the angle of inclination has reached -43°. Loss of altitude ΔH has reached 1,280 m. This indicates that the plane has lost its stable attitude and has begun a nosedive, causing the flight *Ma* value to increase over 0.15 within 20 seconds. From the above, it can be clearly seen that the motion of the airplane has deviated from its stable condition; therefore, under these conditions, the criterion $C_{n\beta.dyn}$ is no longer valid in evaluating flight stability.

B. The Effect of $C_{l\beta}$. Assume $C_{l\beta}=0$. It can be seen from formula (1) that $C_{n\beta.dyn}=C_{n\beta}\cos\alpha\approx C_{n\beta}$. The corresponding $C_{n\beta}$ values can be found from Table 1. Although the contribution of $C_{l\beta}$ to $C_{n\beta.dyn}$ has been lost, $C_{n\beta.dyn}$ is still a positive value. The time-history graph at this time is as shown by the graphs on Fig. 2 composed of the "." symbols. It can be seen from Fig. 2 that when $C_{l\beta}=0$, the rolling/rotation, the sidewise flight, and the pitch motion all show a great change; α, β and ψ all have large-amplitude, high-frequency oscillation. Within 20 seconds, the plane rotates over three times around its longitudinal axis, and the flight path angle of inclination reaches -45°. The loss of altitude reaches 1,620 m, and the *Ma* numbers increase 0.125. In a word, the plane is going down in a nearly spiral attitude. Obviously, under these conditions, $C_{n\beta.dyn}$ is not an accurate criterion in evaluating flight stability.

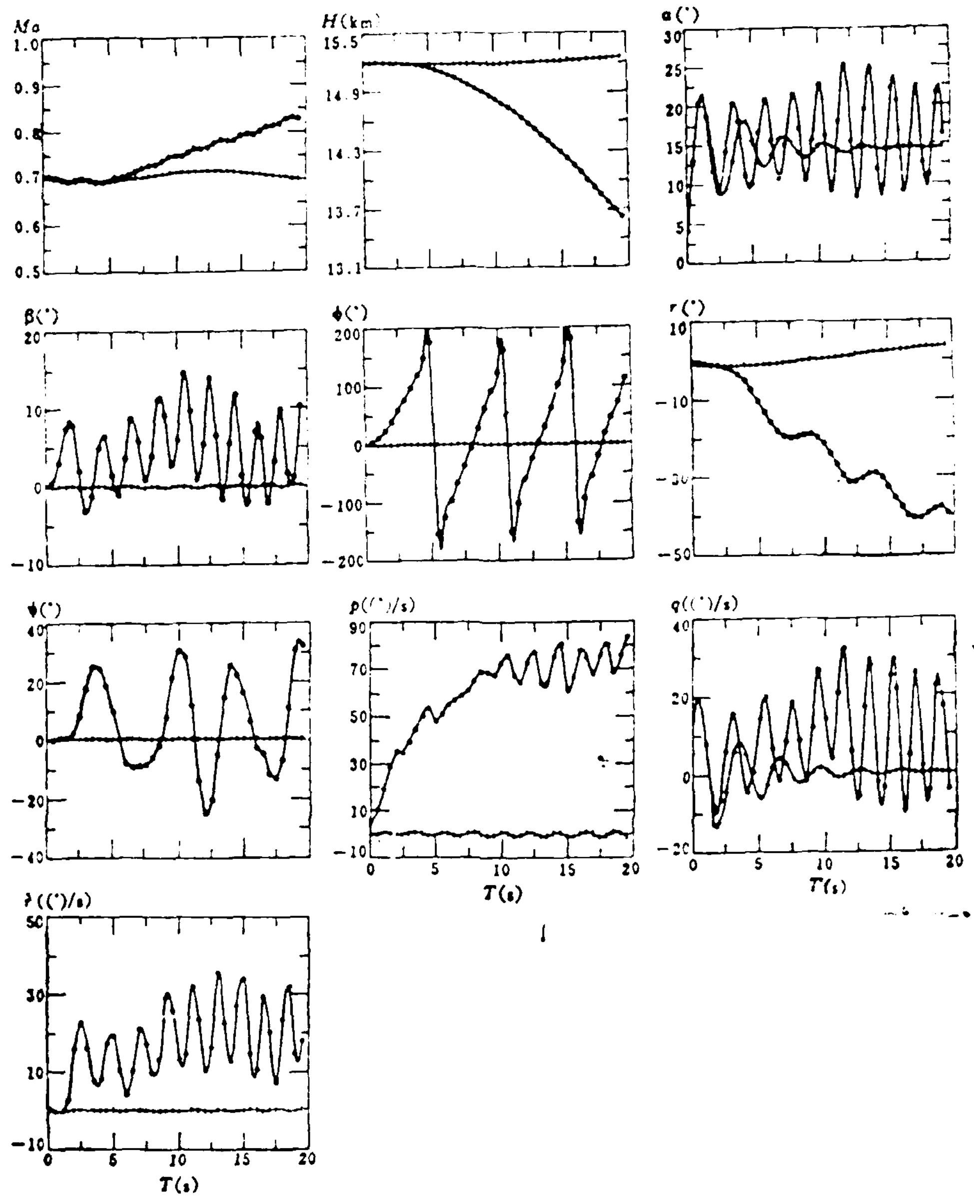

Fig. 2. The effect of C_{lp}.

C. The Effect of C_{nr} and C_{np}. Although these two derivatives do not appear directly in the formula for the criterion $C_{nc.dyn}$, it is possible to deduce that they may have some effect on flight stability from the existence of a certain amount of rolling/rotation and yaw angle velocity in the unstable motion shown in Fig. 1 and 2.

Assume that $C_{nr}=0$ and the other aeronautic data are constant. It can be seen from the calculated results that at this time the time-history deviates very little from the time-history when $C_{nr}\neq 0$. This is because the graphs shown with the "+" symbols are originally stable; the yaw angle velocity *r* is very small, so the effect of C_{nr} on the motion is extremely small.

Assume that when $C_{n\beta}=0$ C_{nr} is doubled in an attempt to compensate for the $C_{n\beta}$ loss. The calculated results show that some of the plane's motion parameters, like β, *p*, *r*, and ϕ, have a rather small change in amplitude, and change slowly; the motion however is still unstable.

From the above calculated results, we can reach the following conclusion: If the airplane is originally stable at a high angle of attack, with a severe damping derivative drop, the plane still has high-angle-of-attack stability. Conversely, if the airplane is not stable at a high angle of attack, even though C_{nr} is increased, it is not possible to effect high-angle-of-attack stability. As regards differences, it is only that the degree of divergence of the parameters is slightly alleviated.

Fig. 3 shows the time-history when $C_{n\beta}$ decreases to half its original value and C_{nr} doubles. At this time, the stability is manifestly improved. Although the motion parameters still show a small divergence, the change is very slow. After 20 seconds, the *Ma* number barely increases 0.06, and the loss of altitude is about 400 m. The drift of angle ϕ is about 110°, not the 360° of Fig. 1. The amplitude variation is also greatly decreased; the amplitude value of β is about 2.4°. If a suitable operation were implemented at this time, it could be expected that the plane would maintain its high-angle-of-attack equilibrium.

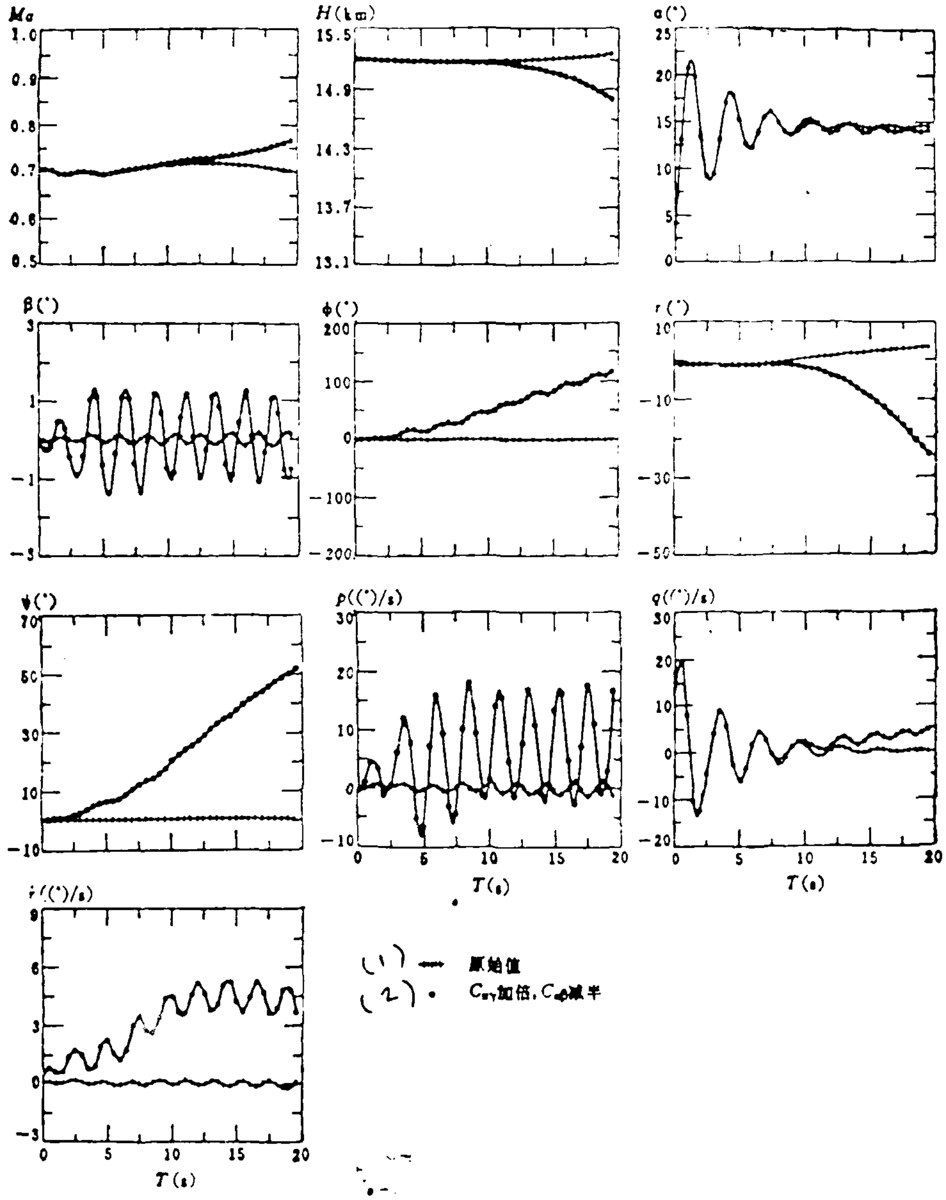

Fig. 3. The effect of C_{nr} and $C_{n\beta}$. Key: (1) Initial values; (2) C_{nr} doubled; $C_{n\beta}$ halved.

Summing up, the effect of C_{nr} on high-angle-of-attack stability is secondary; it is unable to effect a change in the proper quality of motion stability. If however there is an appropriate $C_{n\beta}$ and an appropriate C_{nr} accompanies it, the effect of C_{nr} is not easy to ignore. For this reason, it

is an error to omit all consideration of the effects of C_{nr} from a discussion of the criterion $C_{n\beta.dyn}$.

The effect of C_{lp} on stability can also be analyzed by the method presented above.

4. CONCLUSIONS

1. When an airplane with a high angle of attack pitches downward, the rolling/rotation and yaw stability are related not only with the value of $C_{n\beta.dyn}$, but also with the resulting $C_{n\beta.dyn}$ non-linear derivatives $C_{n\beta}$ and $C_{l\beta}$. That is, not only is the $C_{n\beta.dyn}$ value required; the coupling between $C_{n\beta}$ and $C_{l\beta}$ must also be suitable. Calculations show that even if the value of $C_{n\beta.dyn}$ is maintained constant, when the ratio between $C_{n\beta}$ and $C_{l\beta}$ changes, the high-angle-of-attack stability will also change. For this reason, using only $C_{n\beta.dyn}$ as a criterion to evaluate high-angle-of-attack stability seems to be insufficiently complete.

2. We deduce that the reasons that the criterion $C_{n\beta.dyn}$ cannot evaluate with complete accuracy high-angle-of-attack stability are as follows:

a. The criterion $C_{n\beta.dyn}$ is derived from the damping term c=0 of the small turbulent motion differential formula Holland rolling model state; a series of simplified assumptions is accordingly used. For flight at high angles of attack, these simplified assumptions do not all fit very well. For example, the derivatives $C_{n\beta}$ and $C_{l\beta}$ are no longer constants, but rather functions of α and β. Moreover, even if $\beta=0$, there still exist C_l and C_n, as well as the inertial cross effect, etc.

b. $C_{n\beta.dyn}$, with the assumption that c=0, is obtained by omitting secondary terms and retaining the important terms containing $C_{n\beta}$ and $C_{l\beta}$. When $C_{n\beta.dyn}$ is very small, the order of magnitude of all those omitted terms may be equivalent to or even larger than $C_{n\beta.dyn}$. In this way, it is possible that the sign of the coefficient may be changed.

c. $C_{n\beta}$ and $C_{l\beta}$ are obtained from the graphs of C_n-β and C_l-β; but with a large α, these graphs are quite irregular, effecting a change of sign for $C_{n\beta.dyn}$ on a number of points. On Table 1, however, $C_{n\beta.dyn}$ remains positive.

d. The calculation samples in this paper adequately show that the $C_{n\beta.dyn}$ criterion is not a sufficient substitute for fulfilling the requirements for the derivatives $C_{n\beta}$ and $C_{l\beta}$.

e. Formula (1), which expresses $C_{n\beta.dyn}$, is accurate only on the main inertial axis; for other cases it must be amended [7].

f. The criterion $C_{n\beta.dyn}$ does not take into consideration the effect of C_{nr} and C_{np}.

3. Based on the above analysis, when an airplane's aeronautic data are already known, it is best to evaluate the stability at high angles of attack by means of the time-history curve of calculated motion parameters. Although this method is inelegant, it is more precise and reliable than the $C_{n\beta.dyn}$ criterion.

Because of the limits of the $C_{n\beta.dyn}$ criterion, a variety of methods [8, 9] are now being used to try to find a more nearly ideal criterion, or a supplemental criterion, in the hope of making better predictions regarding high-angle-of-attack stability.

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